TITLE: Investigating the Information Presentation Design Space

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Investigating the Information Presentation Design Space

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Summary: Military systems at all levels of decision making require the ability for the decision maker to find information, query it, seek refinement of it, process it in combination with other information, add value to it, make the decision and communicate the decision to another user. The US Office of Naval Research program in Interactive Multimedia and User-Centered Design supports research in how to employ technological capabilities to enhance a person's abilities to carry out the decision making objective. This paper will employ several research projects from this program to illustrate basic findings that impact how to design systems to meet this objective. Usability objectives require that design address the impact on the user's ability to perform the task. The research reported here, even though in domains or applications that differ from battle management are at the level of studies of enabling understanding of the design space. Reported results provide guidance and suggest how to design the information presentation in the appropriate form for its use.

First, basic assumptions behind development of the program will be described to set the context for the projects. Then, each project will be summarized presenting the research findings. The selected projects provide scientific bases for design decisions that impact how a person can actually use information in different presentation contexts, multimedia documents, multidimensional flat panel displays and in a Responsive Workbench context. Other research includes multiple modalities but will not be discussed here.

Background: The program in Interactive Multimedia and User-Centered Design assumes an integrated multidisciplinary approach to employing cognitive modeling and perceptual understanding in design of task-focused interactive systems. Teams of researchers include cognitive scientists, psychologists, computer scientists, and experts in experimental design in differing combinations. Research projects are theory and hypothesis based allowing effective evaluation to produce better understanding of the human component of a system and hence, contributing to effective system usability and design. Computational cognitive models such as ACT-R (Anderson, 1993) , COGNET (Zachery, Ryder and Hicinbothom, 1999) and EPIC/GLEAN (Meyer and Kieras, 1997a, 1997b) are being developed to provide resources for cognitive appraisal of design decisions.

In addition, building usable systems entails analysis of which modalities are best for what types of information or information use, such as vision, audition, or somatosensory, and what media can provide them, such as a monitor, film, 3-D sound, etc. The space is further complicated in that information presentation can have multiple modes that also differ in how a human can deal with them, such as in the visual modality on a monitor, one can have graphs and text, or text and an animated drawing or only text as modes. These three dimensions, modality, media and mode are being investigated for better understanding of their impact on the user's ability to deal with the information being presented.

With this brief introduction of some of the features of the design space that must be addressed to obtain effective design, the remainder of the paper will illustrate how some of them effect usability of information by presenting research investigating: Interactive multimedia document design; Visual presentation of information using perspective view technology, 2-D or 3-D on flat panels; and Usability in Virtual Environments (VE), user-focused information management in an immersive Responsive Workbench environment.

Paper presented at the RTO HFM Symposium on "Usability of Information in Battle Management Operations", held in Oslo, Norway, 10-13 April 2000, and published in RTO MP-57.

Interactive Multimedia Document Design: Dr. Mary Hegarty (University of California Santa Barbara) and Dr. N. Hari Narayanan (Auburn University) have teamed to investigate a cognitive theoretical model-based multimedia design for manuals that are intended to teach how devices work. Such manuals are a focus of many new requirements that insist on on-line information for training and reference. They are developing methods for presenting information to maximize the user's ability to understand causal relationships from it. Their theory includes a model of human states of comprehension of mechanical devices (the domain of previous work) and their operations. The theory includes a four step process in obtaining understanding of how a device works to be able to apply the understanding to a real world instance of the device. The theory of comprehension includes the following stages: Stage1: **Machine Decomposition** by diagram parsing; Stage 2: **Constructing a Mental Model**-- Making Representational Connections; Stage 3: **Constructing a Static Mental Model**-- Making Referential Connections; Stage 4: **Determining the Causal Chain of Events**; and Stage 5: **Constructing a Dynamic Mental Model** by Mental Simulation and Rule-based Inference (Narayanan and Hegarty, 1998).

Their method for design recognizes cognitive workload factors and attempts to reduce them during reading and studying of the material. They are studying how the integrated placement of text explanations and diagrams, both static and animated, contributes to the understanding of concepts and processes in a hyperlinked document. The model is based on previous work on relative location of text and graphics, showing that text associated with an image must be nearby and that labeling in the text must be clearly visible on the drawing (Hegarty, 1992; Mayer, 1989). They designed on-line documents, based on the theory of stages just described, in the context of understanding how a flushing cistern (toilet) works. Understanding requires inferring causal relationships after the components are recognized and integrating them with world knowledge about water flow and how the mechanical components work in isolation.

The initial design of the hypermedia manual integrating this theory produced a complex set of experiments to validate the theory. The studies compared learning and understanding using a hyperlinked version of the information as well as a static paper version, both were created using the theory of comprehension summarized above. The results indicate that presenting information in a hypermedia manual that includes hyperlinks, colored diagrams, animations (rather than static diagrams) and commentaries (rather than visual text) had no effects on comprehension. The same results were obtained by expository causal link information in the text and in some cases just a labeled diagram alone conveyed the same level of understanding. It seems that the juxtaposition of the structure and content of closely associated material is more important than the form of the document(Hegarty, Quilici, Narayanan, Holmquist and Moreno, 1999).

Among their findings is the fact that they were unable to adequately evaluate their theory and model of design and its predictions in the context of the document. Analysis of their results have suggested other ways to implement their principled theory in the context of interactive multimedia information presentations. Current work continues to find that the "message is more important than the medium" as far as using technology to enhance understanding or comprehension.

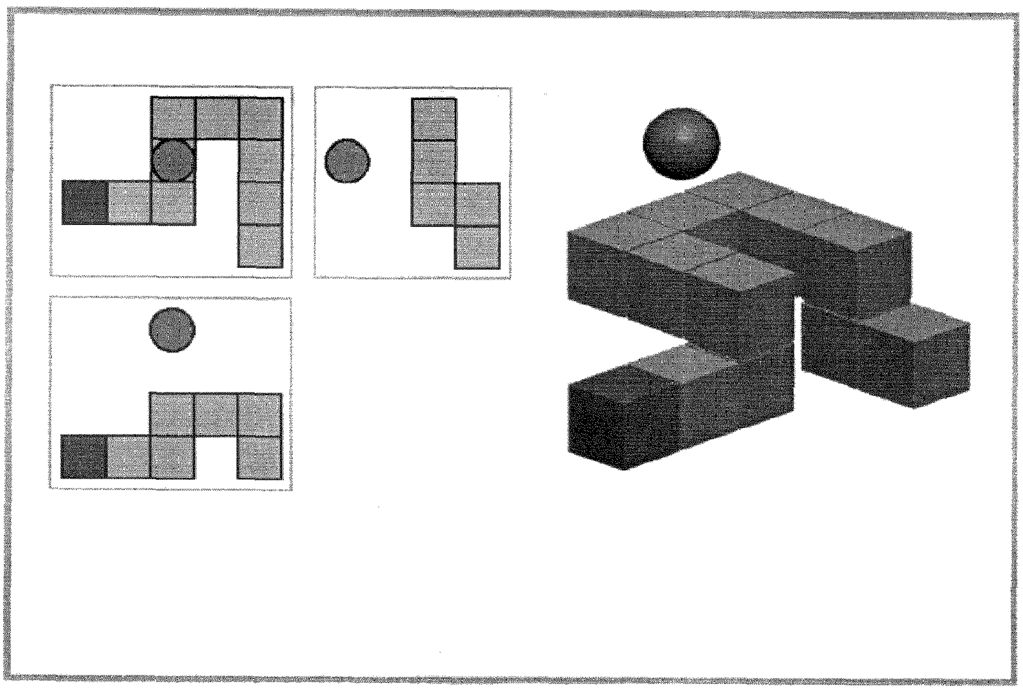
Additionally, Hegarty and Narayanan found, as has been documented elsewhere, that animation does not necessarily aid understanding and that it can confuse the user. Several results indicate that animation must be well integrated with text, or needs to be integrated into material in a manner that requires interaction with the concepts in addition to exploration of the animated rendering of it (Hegarty and Sims, 1994; Kehoe, Stasko, and Taylor, 1999).

They are continuing their investigation on understanding multimedia information using atmospheric weather as their focus. It is something, not directly observable but often visualized for understanding, such as weather front movements and wind speeds and directions. Users will be evaluated for their retention of information and understanding of causal relationships somewhat similar to the original study of how a pumping cistern works.

Others have been studying the effectiveness of animation in learning contexts. The fact that its role is controversial even though assumed to enhance learning has implications for the use of animation in battle management contexts. Dr. John Stasko and his Information Visualization Group (Georgia Institute of Technology) has shown that animation improves understanding in certain contexts and has been exploring how to best provide animation capabilities in learning systems (Stasko, 1996).

Empirical evidence suggests that application of animation in learning and possibly in understanding information in decision making environments may depend on knowledge of the context of application, the mental workload of the person, and whether the person has the ability to mentally visualize and dynamically manipulate it. In understanding algorithms, or software processes, when the person already understands a principle and is able to somehow visualize it, the animation seems to provide enhanced learning (Kehoe, Stasko, and Taylor, 1999). The animation provides additional depth of understanding. This was demonstrated in the context of animations to explain how software algorithms worked, a phenomena that has no real world visualization. It seems that animation is only useful as an enhancement to understanding when the person is already able to mentally visualize the action or concept.

Visual Presentation of Information Using Perspective View Technology: Drs. Michael Cowen (SPAWAR Systems Center-San Diego) and Mark St. John (Pacific Science and Engineering Group, Inc.) are investigating the role display formats play in the ability of a user to access and use information. The issue can be stated as, what type of information is best presented in what format? In a recent technical report (St. John and Cowen, 1999) results from experiments comparing two presentation formats to determine answers to the question about form and available content have shown that in tasks where relative position is important, the multiple projection 2-D presentation provides explicit information that can easily be determined with little error. In contrast, the 3-D presentation has increased ambiguity due to the perspective rendering of the same information. See Figure 1. If the task is to determine the shape or general configuration of an object, then the 3-D is superior to the 2-D multiple view perspective (St. John and Cowen, 1999).



Based on these results, subsequent investigations were carried out to determine the implications of these findings in an Area Air Defense Display. The system design included several 3-D presentations, of terrain and of icons, and the goal was to determine whether, the 3-D perspectives and realism enhanced situation awareness or merely provided a more satisfying feel to the picture. Examples of the icons used in the experiment are provided in Figure 2.

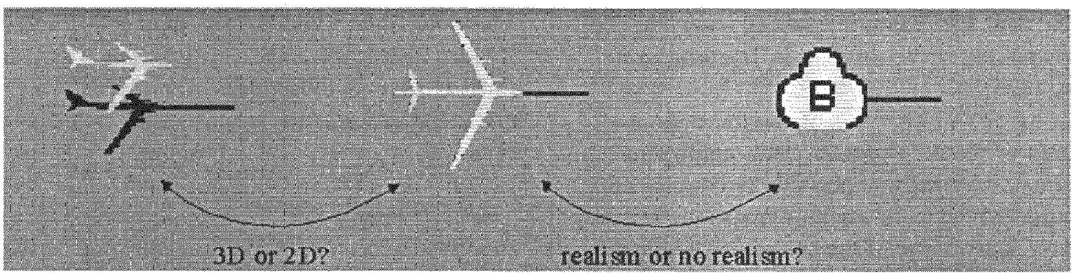


Figure 2: Examples of icon conditions for experiment, left to right, East heading bomber depicted realistically in 3-D, realistically in 2-D, and symbolically or non-realistically (Smallman, Schiller, and Mitchell, 1999).

The icons were overlaid on a flat panel 3-D terrain map in perspective view in one condition, and in planar view in the other two conditions. Tasks include track identification and monitoring to gain situation awareness. Relative ground position was provided by the corresponding shadow on the terrain surface in the perspective view condition. The scenario used was the same for all three conditions, 1) 3-D realistic icons on a 3-D perspective terrain presentation, 2) 3-D realistic icons on a planar terrain presentation (no shadows on surface and bird's eye view) and 3) 2-D non-realistic icons on a planar terrain presentation. Figure 3 shows the 2-D iconic representation on a planar terrain presentation as an example, condition 3 just discussed.

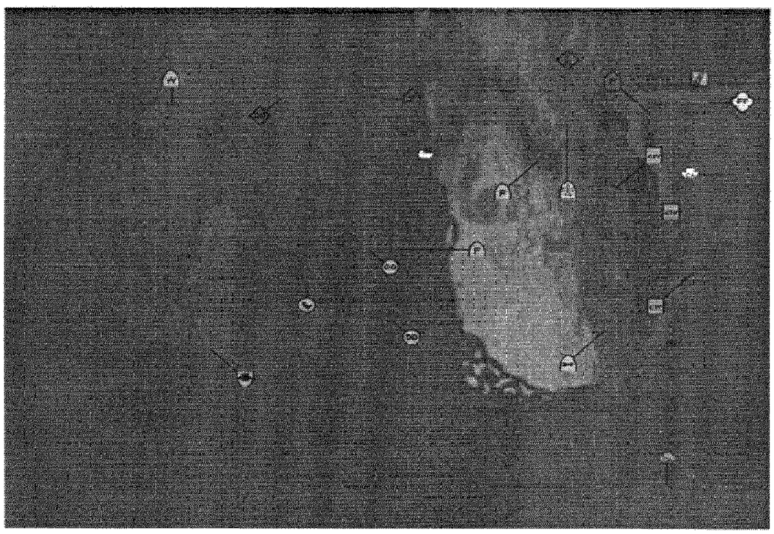


Figure 3: 2-D non-realistic icon view on a planar view map (Smallman, Schiller, and Mitchell, 1999).

Results showed that the 2-D iconic representations are the easiest to remember and produce the fewest errors on identification and reporting of the tested attributes. While the 3-D icon on the 3-D perspective terrain presentation was assumed by the design to provide the best depiction to facilitate the user task, the results showed that the opposite holds. Due to the foreshortening of the perspectives and the nature of the shadow connectivity with the icon, ambiguities are introduced that produce errors in the ability of the user to track the attributes of the object represented by the icon. In addition, when the icons are small due to the distance above the ground, it is very difficult to find the corresponding shadow for the aircraft. Decluttering the image may provide some help, but adds another subtask for the user. Furthermore, in the 3-D case, the light source and its effect on how the shadows appear introduces another aspect of ambiguity in the presentation. Details of these investigations and full results can be found in Smallman, Schiller, Mitchell, 1999.

Battle management systems require many tasks and manipulations of information similar to those that were used in these studies. The usability issues scientifically documented in these studies are important and generally ignored in current designs. Understanding limitations on visual presentation options and how they interact with user tasks and with user capabilities needs to be further explored.

Usability in Virtual Environments: On-going joint research by Dr. Deborah Hix at Virginia Polytechnic Institute and State University (Virginia Tech) and by Dr. Edward Swan II at the Naval Research Laboratory (NRL) focuses on methods for defining usability criteria in virtual environment (VE) design. Their recent award winning paper at the Virtual Reality 99 Conference, (Hix, Swan, Gabbard, McGee, Durbin and King, 1999) exemplifies a four step method of usability design that was verified while applying it in a Naval Battlespace context. This section will begin with an overview of a preliminary investigation into the state of usability for VE and will conclude with an overview of the methodology and its application in the battle management domain.

Initial questions regarding usability issues in VE arose during discussions about device selection and use and the fact that the metaphors for use in VEs are far more complex and allow many new interaction possibilities than any other technology to date. Additional evidence that human usability issues need attention has been documented in the findings that humans subjected to VEs suffer performance effects even up to an hour after they leave the immersion (Kennedy and Stanney, 1996). Previous enhancements to VE technology that focused on presentations, visual, auditory, haptic, and their refinement was able to only ameliorate part of the effect on the user. Since the VE provides an immersive interactive space for design and use, it presents a design challenge along a vast number of dimensions.

An initial effort to document a taxonomy of usability characteristics for VEs intended to begin a dialogue that would aid in understanding the design space at a theoretical level and that would aid in effective VE design. Dr. Hix with her then graduate student, Joseph Gabbard, began their effort to understand the usability issues regarding design of VEs. They did a thorough review of relevant literature, interviewed leading VE researchers and designers, and talked with practitioners and users of VE systems, chiefly in training or mission rehearsal domains. They found that the usability space for VEs included complex interdependencies, among users, user tasks, input devices, output devices, etc. The result of their investigation is a taxonomy of usability methods (Gabbard and Hix, 1997).

Employing known usability methods as a start point, they found that VE expanded their applicability to teams and integrated team tasks, as well as tasks that involved the whole human as opposed to using a system while sitting in front of a monitor. Immersion as part of usability requires new metaphors in thinking about what usability means. The framework in the document organizes user interaction design guidelines and discussion into four major areas: 1) users and user tasks, 2) input mechanisms, 3) virtual models, and 4) presentation mechanisms. All findings are cross-linked and documented with interview explanations or cross-referenced to other related usability. The document intended as a dynamic taxonomy, provides a broad definition of the state of usability in VEs. It is available as a public resource at URL: http://csgrad.cs.vt.edu/~jgabbard/ve/taxonomy. Figure 4 provides an overview of the taxonomy areas. This characterizes the complex design space and illustrates how usability can impact the design of VEs.

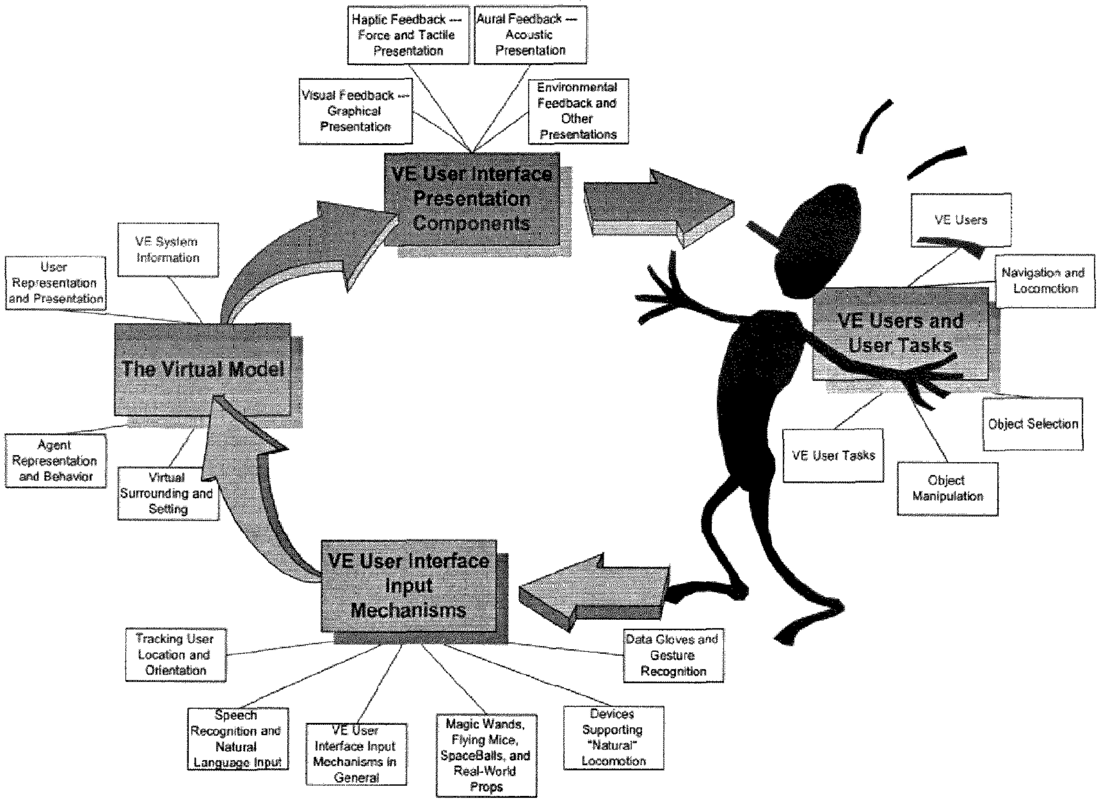


Figure 4: An Overview of the Taxonomy (Gabbard and Hix, 1997).

Follow-on joint work at NRL integrated many of the basic findings into a defined method for usability evaluation in the context of battle information management. This work employed an immersive environment on an Responsive Workbench. In addition to developing a suitable interaction device, the effort took approximately nine months to apply the usability method, validating it as the work progressed and in the end, producing a system that is ready for summative evaluation in the application domain.

This development has supported the fact that by carrying out the up-front usability design methods, life-cycle cost reduction can be realized. A few of the many discoveries in the context of this work will be summarized. Below, Figure 5, is the workbench environment, Dragon (Durbin et al., 1998), including the terrain and object renderings that form the basis of the design solution. It is the result of a successful application of the design, test, design cycle of usability assessment. Details of the effort can be found in the Virtual Reality 99 paper referenced above. The methodology is elaborated in Gabbard, Hix and Swan, 1999. The usability method includes a four step assessment, based on the design space presented in Figure 4. The user-centered methodology assumes sequential performance of the following 4 steps: 1) user task analysis, 2) expert guidelines-based evaluation, 3) formative user-centered evaluation, and 4) summative evaluation.

Cyclic evaluations are performed as design problems arise. As more problems are eliminated in the early phases, the cost of implementation and subsequent possible modification are reduced. The four steps will be briefly described In the context of developing the interface design for navigating within the Dragon workbench environment.

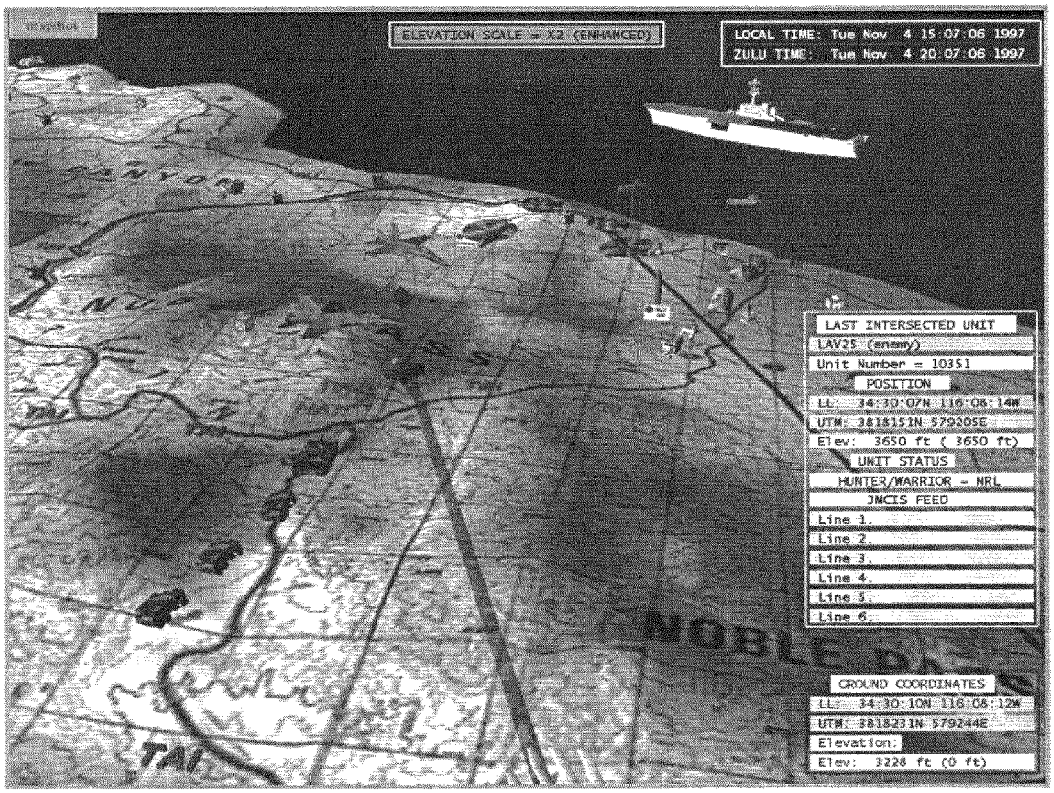


Figure 5: Dragon Responsive Workbench Design (Hix et al., 1999)

1.

1. **User task analysis:** must include an understanding that is as comprehensive as possible of the tasks the user will be doing and the goals of the total system use to achieve good user-centered design. It was found very early in working with the workbench, that the ability of the user to move around, locomote, to find the information they need is critical to any other tasks. Therefore, the task selected to implement and evaluate the method became locomotion.
2. **Expert guidelines-based evaluation:** identifies potential usability problems by evaluating a user interaction design against what is known by experts to be sound design principles. Any violations are revisited and the design is redone to address them. Multiple experts perform the evaluation, independently and then in joint discussion. During this phase in the design of Dragon, experts discovered a major problem of poor mapping of locomotion tasks (pan, zoom, pitch, heading) to flight stick buttons as well as problems with inadequate graphical and textual feedback to the user about the locomotion.
3. **Formative user-centered evaluation:** requires careful definition of scenarios that will exercise the interface under the set of tasks included in the design. In the Dragon design of locomotion, the initial control was to allow the user to move the map relative to themselves. During formative evaluation, users indicated they wanted to be able to fly over the terrain. This input suggested a different design that was developed to allow movement in exocentric (the map movement) and egocentric ways(the fly –over). Subsequent evaluations were carried out to build the right responsiveness into the interface to adequately capture the control from the user's perspective for both these metaphors. This evaluation includes data collection about user's performance that guides the design for the system.

4. **Summative evaluation:** requires comparative evaluation between several competing designs. This is a formal evaluation of the implemented user-focused interface. The affects of exocentric vs egocentric control are one variation being studied in Dragon. To effectively test this, all actions must be accomplishable in both systems to be able to compare measures that will determine the best design. Speed of problem solving is one such measure as is correctness of solution. For this type of evaluation an adequate scenario test set must be defined that drives the interface use in ways that will stress its functionality to firmly determine the best solution. Summative evaluation focusing on egocentric versus exocentric control is currently underway (Gabbard, Hix and Swan, 1999.)

The importance of this applied methodology is that the right level of detailed evaluation is performed at the right time during the design, saving extensive redesign to correct problems late in the cycle. The possibility of achieving an adequate and effective system is greatly enhanced and at a much reduced overall cost.

Conclusions: Usability methods have many applications in military systems. We are just beginning to understand some of the underlying cognitive aspects that are reflected in how people can obtain and use information. As more interdisciplinary conversations occur between cognitive scientists, usability engineers, human-computer interface designers and domain experts we will see a positive change in the design of systems—more usable by more people without restrictive selection criteria and the overall result will be a cost reduction in the life-cycle costs of the systems.

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